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STUDY OF ADHESION AND COHESION IN VACUUM

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AEROSPACE GROUP
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HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA

HUGHES AIRCRAFT COMPANY
AEROSPACE GROUP
MATERIALS TECHNOLOGY DEPARTMENT
Culver City, California

STUDY OF ADHESION AND COHESION IN VACUUM

by

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1 January 1965

Fifth Quarterly Report

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George C. Marshall Space Flight Center
Huntsville, Alabama

Approved: [signature]
W. H. Colner, Manager
Materials Technology Department

FOREWORD

This report was prepared by the Hughes Aircraft Company to cover work completed during the period 1 October 1964 to 1 January 1965, under a NASA contract for the study of adhesion and cohesion of metals in vacuum. This contract is sponsored by the George C. Marshall Space Flight Center, NASA, Huntsville, Alabama, with Mr. Keith Demorest as the Contracting Officer's Technical Representative.

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ABSTRACT

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Adhesion and cohesion tests made under static loading conditions in vacuum showed no tendency for 2014 aluminum alloy to bond to itself or the other test materials when loaded within its elastic limit at 150°C. Bonding of these material couples generally occurred at 300°C in vacuum. It was also determined that 2014 aluminum would bond to itself in air in the same period of time and under the same load as it bonded in vacuum. The strengths of the vacuum-bonded specimens appeared higher.

Cohesion of copper did not occur in vacuum at 150°C but did occur at 300°C. There was no indication of cohesion of the titanium alloy couple tested at 500°C.

The equipment design modification for incorporating vibratory motion to the test specimens was completed and fabrication was commenced. The drive mechanism was designed and built.

INTRODUCTION

The purpose of this program is to determine the temperature and time conditions under which adhesion or cohesion of structural metals in a vacuum occurs. The data developed from this study will provide spacecraft designers with engineering data required to insure separation of instrument capsules and other components from spacecraft which have been exposed to a hard vacuum.

The program of the first year included design and fabrication of a vacuum test chamber incorporating the following features: (1) an environmental pressure not greater than 5×10^{-9} torr, (2) a static loading device capable of providing and measuring tensile and compressive pressures of from 0 to 100,000 psi and (3) a range of testing temperatures from 25°C to 500°C.

Tests were made by application of compressive loads to contacting test specimens in the vacuum chamber for a given time period. Then the tensile force required to separate the two test specimens was measured to determine the extent of adhesion or cohesion.

Thirteen different combinations of metal couples were evaluated. Material screening tests were performed first under the most severe environmental conditions of contact pressure and temperature to allow concentration of effort upon those couples that caused the most difficulty. Material combinations that bonded under the most severe conditions were then tested at the next lower specified temperature in order to arrive at the threshold conditions at which bonding would not occur. This test philosophy is based on the assumption that if materials loaded to 80 percent of their yield strength or creep strength (whichever is lower) do not bond at a given temperature, they likewise will not bond at lower temperatures in similar time periods.

The objective of the second year's program is similar to that of the first year with the exception that lateral motion will be applied to the test specimens while they are pressed together under a compressive load. This program includes modification of the test apparatus to provide vibratory-rotary motion of ±2 to 5 degrees at 1 to 100 cps, or as approved. The number of test couples to be studied in this mode is eleven. The time, temperature, and loads at which adhesion or cohesion occurs under vibratory loading will be determined.

WORK ACCOMPLISHED PRIOR TO CURRENT REPORTING PERIOD

Work performed prior to this reporting period consisted of design and building of test equipment for the study of adhesion and cohesion of metals under static loading in vacuum. Thirteen material combinations were studied and for eight of these material combinations, parameters were established at which adhesion or cohesion did not occur. Bonding was observed at 300°C for the following couples: (1) copper to copper, (2) 2014 aluminum to 2014 aluminum, (3) 2014 aluminum to 304 steel, (4) 2014 aluminum to A286 steel, and (5) 2014 aluminum to René 41.

The design modification for introducing vibratory motion was substantially completed. Provisions were made to incorporate a titanium sublimation pump to the vacuum system to increase the pumping speed.

RESULTS OF STATIC ADHESION AND COHESION TESTS

The adhesion and cohesion test data are summarized in Table I and the physical measurements of the test specimens are shown in Table II.

COUPLES CONTAINING 2014 ALUMINUM

The continued tests in which 2014 aluminum was one member of a couple showed no tendency for the alloy to bond to other metals when loaded at nominal loads of 25,500 psi at 150°C for 70,000 seconds. In the majority of tests of 2014 aluminum at 300°C and loads of 3440 psi nominal, bonding has occurred with all other alloys. The test of 2014 aluminum to René 41 in Table I (in which no adhesion was observed in a 70,000-second exposure) is an exception. In three separate tests at 300°C of this material combination, adhesion occurred in two of the tests. In the test of 2014 aluminum/304 steel couple, a malfunction of the strain gage circuit caused overloading of the material and the elastic limit of the aluminum alloy was exceeded.

6Al-4V TITANIUM COUPLES

Further testing of the 6Al-4V-titanium alloy resulted in no cohesion in the maximum time period at temperatures up to 300°C. No cohesion occurred at 500°C in time periods up to and including 10,000 seconds. The 70,000-second exposure was not completed due to accidental damage to the specimens.

COPPER COUPLES

The copper to copper couple showed no cohesion when loaded to 5600 psi at 150°C for the maximum time period. The 300°C test resulted in cohesion at a load of 1790 psi. In a previous test at this temperature, cohesion was obtained at 3600 psi.

	Test Time (seconds)	Temperature (°C)	Load (psi)	Pressure (10^{-9} torr)	Bond Strength (psi)	Remarks
Top Specimen	10	150	25,500	5	)	--
Al-23 / 2014 Al	100	150	25,500	6	0	--
	1,000	150	24,900 - 25,900	7	0	
Lower Specimen	10,000	150	24,900 - 26,100	7	0	--
Ti-12 / Ti-6 Al-4V	70,000	150	24,900 - 25,900	7	0	--
Top Specimen	10	150	25,500	4	0	--
Al-24 / 2014 Al	100	150	25,500	4	0	--
	1,000	150	24,900 - 26,100	5	0	--
Lower Specimen	10,000	150	23,300 - 27,000	6	0	--
R-5 / René 41	70,000	150	25,300 - 26,600	5	0	--
Top Specimen	10	300	3,440	7	0	--
Al-24 / 2014 Al	100	300	3,440	8	0	--
	1,000	300	3,440	8 - 31	0	--
Lower Specimen	10,000	300	3,150 - 3,730	8 - 23	0	--
R-5 / René 41	70,000	300	3,070 - 3,730	6 - 9	0	--

Table I. Test data.

	Test Time (seconds)	Temper-ature (°C)	Load (psi)	Pressure (10^{-9} torr)	Bond Strength (psi)	Remarks
Top Specimen	10	150	83,000	3	0	--
Ti-8 / Ti-6 Al-4V	100	150	83,000	3	0	--
	1,000	150	83,000	6	0	--
Lower Specimen	10,000	150	75,700 - 84,300	4	0	--
Ti-11 / Ti-6 Al-4V	70,000	150	77,800 - 83,000	4	0	--
Top Specimen	10	300	69,000	8	0	--
Ti-8 / Ti-6 Al-4V	100	300	69,000	12	0	--
	1,000	300	68,200 - 71,600	32 - 50	0	--
Lower Specimen	10,000	290 - 310	65,400 - 69,400	19 - 32	0	--
Ti-11 / Ti-6 Al-4V	70 000	290 - 310	68,200 - 70,700	6 - 12	0	--
Top Specimen	10	500	29,000	6×10^{-7}	0	After the 10,000-sec test the upper specimen fell onto the lower specimen and damaged it resulting in increased surface contact area.
Ti-8 / Ti-6 Al-4V	100	500	29,000	4.6×10^{-7}	0	
	1,000	500	29,000	4.6 to 7×10^{-7}	0	
Lower Specimen	10,000	500	27,700 - 30,700	5.5 to 10×10^{-7}		
Ti-11 / Ti-6 Al-4V						

Table I (continued)

	Test Time (seconds)	Temperature (°C)	Load (psi)	Pressure (10^{-9} torr)	Bond Strength (psi)	Remarks
Top Specimen	10	150	25,500	3.5	0	--
Al-25 / 2014 Al	100	150	25,500	3.5	0	--
	1,000	150	24,900 - 27,000	3.5	0	--
Lower Specimen	10,000	150	24,000 - 26,500	4	0	--
S3-11 / 304 Steel	70,000	150	24,700 - 26,400	4 - 6	0	--
Top Specimen	10	300	3,440	8	0	--
Al-25 / 2014 Al	100	300	3,440	8	0	--
	1,000	300	--	7.5	165	--
Lower Specimen						
S3-11 / 304 Steel						
Top Specimen	10	150	5,600	4	0	--
C-2 / Copper	100	150	5,600	4	0	--
	1,000	150	5,300 - 5,800	4	0	--
Lower Specimen	10,000	150	5,100 - 5,700	4	0	--
C-22 / Copper	70,000	150	5,500 - 5,700	3.5 - 4	0	--
Top Specimen	10	300	1,790	3.5	0	--
C-2 / Copper	100	300	1,800	3.5	0	--
	1,000	295 - 310	1,790	3.5	0	--
Lower Specimen	10,000	295 - 305	1,790	3.5	0	--
C-22 / Copper	70,000	300	1,790	3.5	160	--

Table I (continued)

Couple	Material	Specimen Number	Specimen Height (Inch)		Specimen Diameter (Inch)		Specimen Hardness (Rockwell)		Specimen Finish (RMS)	
			Before	After	Before	After	Before	After	Before	After
32	2014 Aluminum	Al-23	0.824	0.824	0.254	0.254	15T-86	15T-60	24	25
	Ti-6 Al-4V	Ti-12	0.823	0.823	0.564	0.564	RC-37	RC-38	21	24
33	2014 Aluminum	Al-24	0.823	0.820	0.254	0.256	15T-87	15T-61	26	33
	Rene 41	R-5	0.824	0.824	0.566	0.566	RC-43	RC-43	32	32
34	Ti-6 Al-4V	Ti-8	0.824	0.725	0.177	0.257	RC-36	RC-36	30	*
	Ti-6 Al-4V	Ti-11	0.823	0.823	0.565	0.565	RC-37	RC-37	21	*
35	2014 Aluminum	Al-25	0.824	0.798	0.254	0.275	15T-87	15T-62	23	19
	304 Steel	S_3-11	0.824	0.824	0.565	0.565	30T-80	30T-82	28	35
36	Copper	C-2	0.824	0.824	0.357	0.360	15T-79	15T-34	--	14
	Copper	C-22	0.821	0.821	0.567	0.567	15T-80	15T-37	27	21

*Surface finish not measured due to damaged surfaces of specimens. Deformation of specimen Ti-8 was due to accidentally dropping top specimen on to lower specimen.

Table II. Physical measurements of test specimens.

SUMMARY OF VACUUM TESTS

Based on the data obtained to date, it appears that couples containing 2014 aluminum as one member and copper to copper couples are the only couples in which adhesion or cohesion is a problem with static loading. These couples bonded at 300°C when loaded within their elastic limits, but did not bond at 150°C. All other couples did not bond at temperatures of 500°C.

COHESION IN AIR

Inasmuch as aluminum alloys form a protective oxide which does not decompose by volatilization in a vacuum, it would appear that this protective film would present a barrier to hinder bonding. Since the tests in vacuum have indicated that bonding does occur, the evidence points to some other mechanism for disruption of the oxide film to allow metal to metal contact. Other probable mechanisms are diffusion of the oxide into the metal or mechanical disruption by the yielding of the localized asperities on the surface to cause fracture of the brittle oxide. From these considerations, it is conceivable that bonding could be obtained in ambient atmospheres even though the bulk yield strength of the aluminum is not exceeded. To substantiate this theory, bonding tests of 2014 aluminum to itself in air were made. These tests were not made using the adhesion and cohesion test apparatus and therefore it was not convenient to use the same design of test specimens. In the tests made in air, lap-shear specimens having faying surfaces of 1 square inch were used. Three couples were simultaneously heated at 300°C and 3500 psi for 19 hours. The shear strength of the bonds when cooled to room temperature varied from a value so low that it broke in handling to a maximum of 205 psi. These values cannot be correlated with the tensile strengths of the bonds tested at 300 C in the vacuum apparatus, but the latter are probably much stronger. This serves to indicate that cohesion of aluminum alloy can take place in air without exceeding the bulk yield strength of the alloy.

DESIGN AND FABRICATION OF APPARATUS

A. TITANIUM SUBLIMATION PUMP

The stainless steel pump body was leak checked after welding and was found to be vacuum tight. Copper tubing was then silver-soldered to the outside of the pump body. This tubing carries water to cool the pump body.

After being electropolished, the pump was connected between the 100 liter/sec ion-pump and the working chamber Brief activation of one of the titanium filaments demonstrated that the electrical circuits were functioning properly. To prepare the pump for use, the pump body was then baked to remove adsorbed gases from its walls.

B. DYNAMIC TEST APPARATUS

The design drawings for the design modification described in the Fourth Quarterly Report were finished and fabrication of the parts began. The front of the vacuum hub chamber was manufactured first so that two metal bellows could be welded to it. This welding was completed and leak checked, as was the bellows unit which will allow vertical motion of the upper specimen. Manufacture of the remaining metal parts was completed just as the reporting period ended.

Heater bodies and lids, insulators, and hub support pads made from high density alumina were completed.

The first pair of test specimens will be used in checking the alignment of the apparatus after it is assembled. Fabrication of this pair from 2014-T6 aluminum alloy was started during the reporting period.

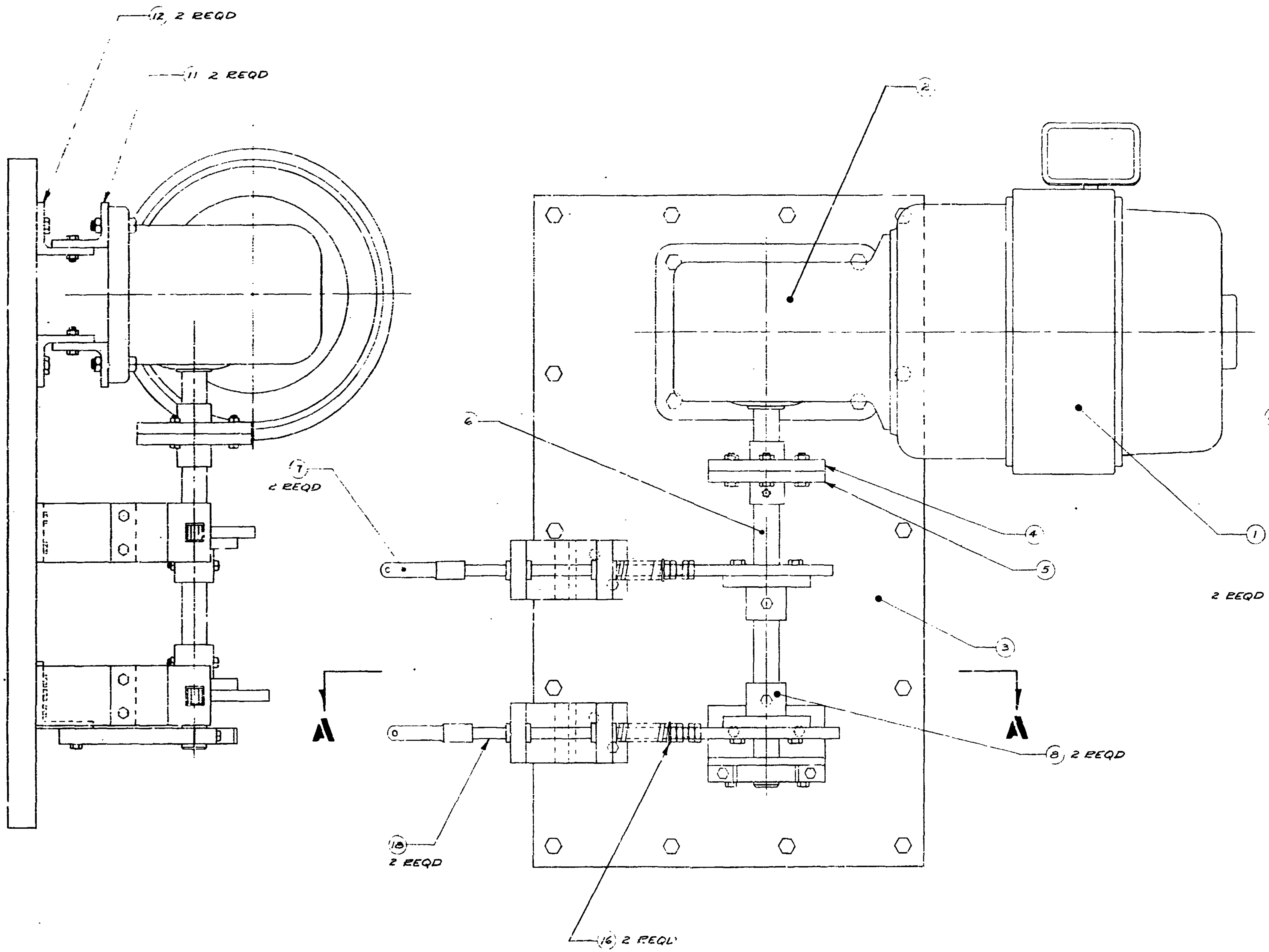
C. DRIVE MECHANISM

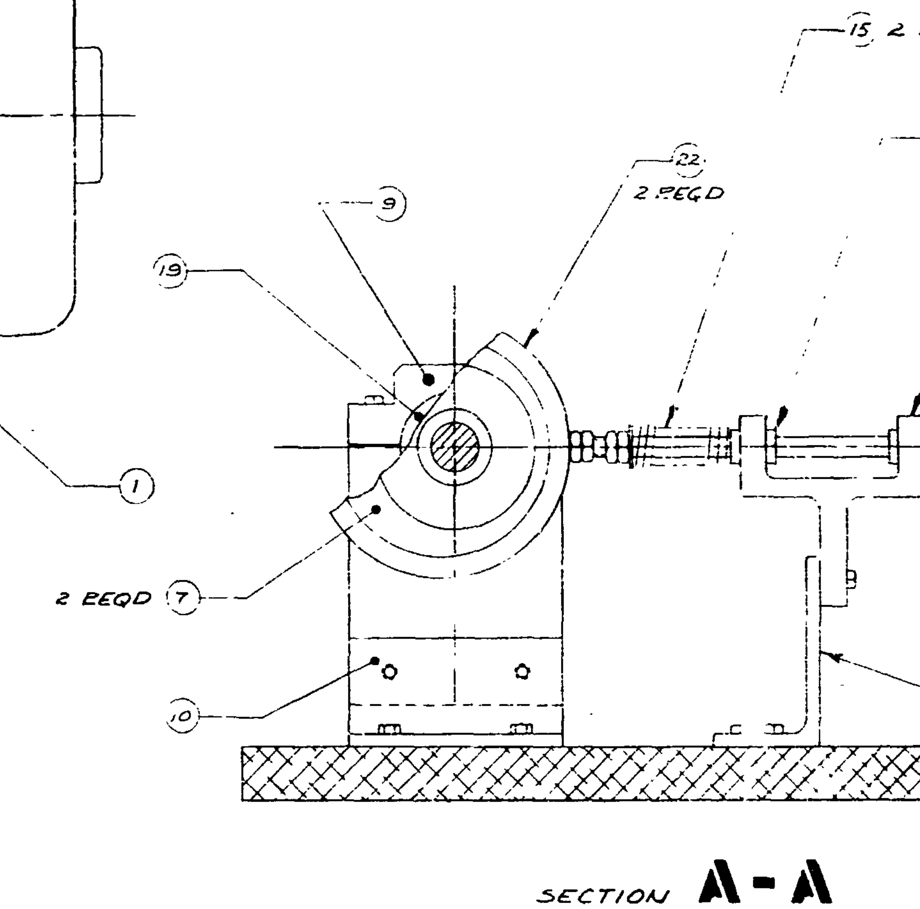
Figure 1 shows the drive mechanism assembly which was designed during the reporting period. All drawings were completed and all of the parts were fabricated.

As shown in Figure 1, a 1750-rpm motor of 1 HP (Boston 29494) powers the drive mechanism. A 10:1 flanged reductor (Boston UF121E) provides 376 inch-pounds of torque at 175 rpm at its output shaft. This shaft is coupled to a camshaft (item 6 in Figure 1) which rotates two cams (item 7) against the inner races of two annular ball bearings (item 22). The force is transmitted through each bearing to a drive rod (item 18). Each of the two clevises (item 17) transmits the driving force from the drive rod (item 18) through a pin to a shaft which passes through bellows into the vacuum chamber.

Each spring (item 15) provides a force to return the associated drive rod to its initial position while the other drive rod is being pushed. That is, the springs ensure that the drive rods are always in contact with the outer races of the cams.

The speed of the motor is controlled between 0 and 1750 rpm by a 1 HP "Ratiotrol" (Boston R-100). The motor, reductor, speed control, and all bearings shown in the drawing were ordered and received during the reporting period.



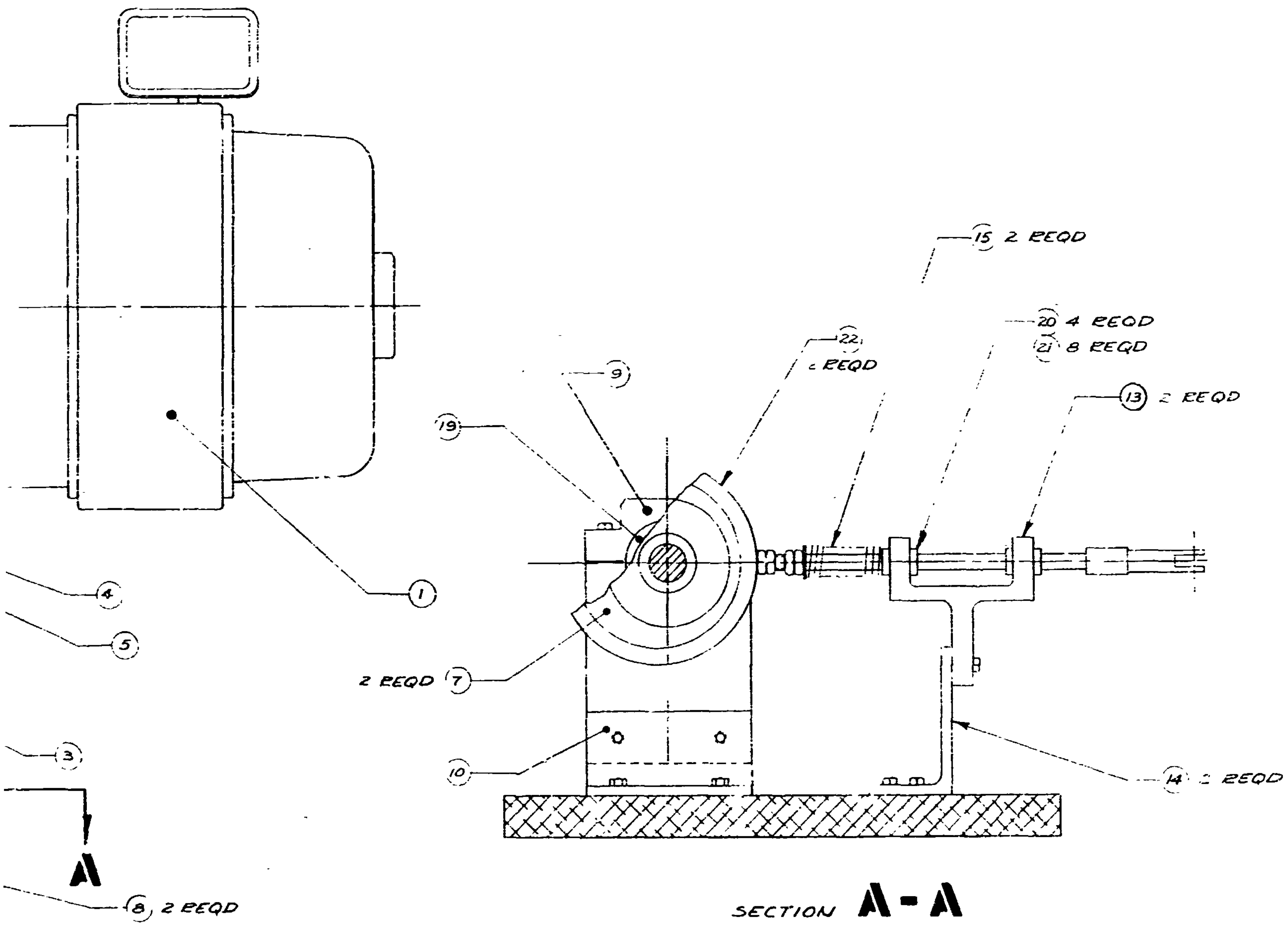


3 PROCURE FROM KAYDON ENGINEERIN MUSKEGON, MICH.

2 PROCURE FROM THOMSON INDUSTRIES MANHASSET, N.Y.

1 PROCURE FROM BOSTON GEAR WORKS,

NOTES: U.O.S



Note	QTY REQD	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	ZONE	ITEM NO.
	1		1/4-20UNC-2B SET SCREW		36
	17		1/4-20UNC-2B HEX NUT		35
	26		3/8-16UNC-2B HEX NUT		34
	33		.25 I.D SPLIT LOCKWASHER		33
	18		.38 I.D. SPLIT LOCKWASHER		32
	43		.25 I.D. FLAT WASHER (STEEL)		31
	18		.38 I.D. FLAT WASHER (STEEL)		30
	8		1/4-20UNC-2A BOLT, .75 LONG (HEX HEAD)		29
	2		1/4-20UNC-2A BOLT, 1.00 LONG (HEX HEAD)		28
	5		1/4-20UNC 2A BOLT, 1.25 LONG (HEX HEAD)		27
	2		1/4-20UNC-2A BOLT, 1.75 LONG (HEX HEAD)		26
	6		1/4-20UNC-2A BOLT, 2.50 LONG (HEX HEAD)		25
	4		3/8-16UNC-2A BOLT, 2.00 LONG (HEX HEAD)		24
	14		3/8-16UNC-2A BOLT, 2.50 LONG (HEX HEAD)		23
3	2	KC40CP	BEARING, BALL, ANNULAR		22
2	8	W-375	EXTERNAL RETAINING RING		21
2	4	A-61014	BALL BUSHING		20
1	1	1640	BEARING, BALL, ANNULAR		19
	2	-78	DRIVE ROD		18
	2	-71	CLEVIS		17
	2	-50	WASHER, SPRING RETAINER		16
	2	-51	SPRING COMPRESSION		15
	1	-54	YOKE SUPPORT		14
	1	-55	YOKE		13
	2	-56	BRACKET MOUNT REDUCTOR--LOWER		12
	2	-57	BRACKET MOUNT REDUCTOR--UPPER		11
	1	-60	SUPPORT BASE		10
	1	-61	BEARING SUPPORT ASSY		9
	2	-62	CAM COLLAR		8
	2	-63	CAM		7
	1	-64	CAM SHAFT		6
	1	65	HUB--SHAFT FLANGE		5
	1	-66	HUB--REDUCTOR FLANGE		4
	1	SP205941-53	MOUNTING BASE PLATE		3
1	1	UF121E	FLANGED REDUCTOR		2
1	1	29494	MOTOR (1 HP)		1

LIST OF MATERIALS

DRAWN S. FUJIKAWA	DATE 5 NOV '64	HUGHES	HUGHES AIRCRAFT COMPANY, CULVER CITY, CALIF.
CHECKED J GARVEY	11-9-64	TITLE MOTOR DRIVE ASSY	
APPROVED		CODE IDENT NO. 82577	SIZE J — NUMBER SP205941-67
APPROVED		SCALE 1/2	SHEET

3 PROCURE FROM KAYDON ENGINEERING CORP., MUSKEGON, MICH.

2 PROCURE FROM THOMSON INDUSTRIES CORP., MANHASSET, N.Y.

1 PROCURE FROM BOSTON GEAR WORKS, QUINCY, MASS.

NOTES: U.O.S

Figure 1. Motor drive assembly.

WORK PLANNED FOR NEXT QUARTER

The work planned for the next quarter is:

(1) Complete static adhesion and cohesion tests.

(2) Complete fabrication of dynamic test apparatus in the following sequence:

- (a) Assemble subassembly containing all of the moving parts.
- (b) Attach subassembly to drive mechanism and check functioning.
- (c) Weld remainder of assembly to complete the vacuum chamber, leak check, and electropolish.

(3) Commence dynamic testing.

(4) Determine optimum sublimation rates for the titanium sublimation pump to obtain the best pumping speeds.

VISITS

Mr. Keith Demorest, the Contracting Officer's Technical Representative visited the Hughes Aircraft Company on 5 and 6 October to review the equipment modification design and progress of the static tests.